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ELECTRICAL DIAGNOSTIC TESTING OF 5 kV CABLES - LAKEVIEW TGS U5 AND U6

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ABSTRACT

As part of the Lakeview TGS rehabilitation program, tests were performed on four selected 5 kV power cable circuits to assess their condition. Both diagnostic and destructive electrical terminal tests were carried out in-situ on the unshielded cables and, in the laboratory, in a shielded configuration. The results indicate that for triplex configurations, testing phase-to-phase was a realistic alternative, with good agreement between in-situ and laboratory measurements. None of the conventional diagnostic measurements (dc insulation resistance and polarization index, partial discharge, capacitance, dissipation factor) was sensitive to cable deterioration. A substantial decrease in ac breakdown was found for cables exposed to moist environments. The same problems will likely be found on other 5 kV cables in underground/wet locations and these cables should be replaced. 600 V, and lower voltage cables, would not be affected and with the possible exception of local overheating, would be expected to be in satisfactory condition.

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INTRODUCTION

Lakeview TGS is currently undergoing a rehabilitation program. As part of these activities, tests were planned to assess the condition of the power plant cables. In consultation with London Monenco, the 5 kV power cables were selected as representative of the plant as a whole and subjected to electrical and mechanical testing.

Diagnostic and destructive tests were carried out in-situ on four 5 kV cable circuits at Lakeview TGS. The cables were used to energize a Condensate Pump Motor (EA5007), an ID Fan Motor (FA5018), and a Circulating Water Pump Motor (FA5004). A short section of a Boiler Feed Pump motor cable, removed from the power house at G76 column, was also tested, but only in the laboratory. All cables were triplex, unshielded (4/0) and jacketed. The butyl rubber insulated (4.7 mm) cables were manufactured by Canada Wire in approximately 1964. Following in-situ testing, the three cables were removed and taken to Research for further tests. Two cables were pulled intact; one cable was cut into two sections because of its length. A length of approximately 15 m was cut from each of the 4 cables for testing. Although the electrical test methods are used extensively, it is not known how applicable these methods would be to assess the condition of generating station cables. Many station cables, including the circuits described here, are unshielded and portions of cable will not be effectively stressed during any electrical test. Comparison with laboratory data obtained on shielded configurations is a critical element of the test program undertaken.

The present report details the findings of the test program.

TEST PROCEDURES

For the in-situ tests, the cables were disconnected from their respective switchgear. A length of each cable was removed to do the tests more conveniently. The cables ran in underground conduit to each motor. Nondestructive tests included partial discharge (PD) measurements, insulation resistance testing, and capacitance and dissipation factor measurements. The destructive tests consisted of breaking the cables down with high ac and dc voltage. Cable lengths were determined by low voltage pulse propagation measurements. The condensate pump motor cable was approximately 75 feet long, the ID fan motor cable was approximately 450 feet long and the circulating water pump motor cable was about 1000 feet in length.

In the laboratory tests, the same measurements were repeated, including partial discharge measurements, insulation resistance test and capacitance and dissipation factor. However, the unshielded cables were individually wrapped in aluminum foil and then tested in a grounded cable tray.

The partial discharge magnitudes were measured with a custom detector consisting of a 375 pF portable coupler, a high-pass filter and an oscilloscope. The capacitance and dissipation factor (DF) were measured using a Guildline capacitance bridge. A Criterion 5 kV megger set was used at 1 kV to do the megger tests. The ac breakdown tests were done with a 150 kV Hipotronics set. The dc breakdowns were done with a 150 kV dc Glassman power supply. All tests were done with one phase energized and the other two phases grounded. Where possible, all three phases were broken down.

Physical tests were carried out by the Materials Chemistry Section on buffed specimens cut from the butyl insulation.

RESULTS AND DISCUSSION

The test results are presented in Tables 1 to 5. The results are organized to provide a direct comparison between shielded and unshielded configurations and where practical among the four cable circuits.

Breakdown values (Table 1) fell into two distinct categories, with either very high or very low values for both ac and dc. The high breakdown values ranged from 65 to 85 kVac and dc withstands of greater than 150 kV. The lower values ranged from 40 to 45 kVac and 32 to 54 kVdc. The very low values (<10kV) were attributed to damage to the phase under test from a prior breakdown on an adjacent phase (the location of failures was not determined). Results for in-situ and laboratory testing were quite consistent, e.g., on the CCW and IFM cables. While the cables were unshielded and thus lacked a well-defined, continuous ground plane, the results obtained here indicate that for multi-conductor configurations (e.g., triplex) testing phase-to-phase was a realistic alternative by providing a better defined stress across the insulation.

The breakdowns obtained on the two segments of the CCW cables are most interesting as one section fell into the high withstand category while the second section exhibited some of the lowest breakdowns recorded. Such results are consistent with localized deterioration, possibly associated with an underground location. Low breakdown values have been reported on underground distribution systems, reportedly as a result of water treeing. While a detailed examination was carried out on the cables exhibiting low dielectric breakdown, no evidence of water treeing could be detected. However, the butyl compounds used were highly filled, limiting the extent of any microscopic examination; although fluorescent dye techniques were used, no water tree was found. Physical testing of the cable insulation yielded no evidence of a drastic reduction in flexibility and/or physical properties. Nonetheless the construction type used in these cables, notably the taped strand shield, is particularly conducive to water treeing and this remains the likely cause of reduced breakdown strength.

The condition of the four cables was generally good and physical properties remained good. Tensile elongation at break varied from 425 to 475%, with tensile strength ranging from 4.4 to 6.2 MPa. While no direct comparison to an unaged cable could be made, further accelerated oven aging of one 25 year-old cable by the cable manufacturer indicated that the insulation would still pass the aging requirement specified at the time of manufacture.

The corresponding non-destructive diagnostic test results are given in Tables 2 to 5. There is clearly no obvious correlation between any of the diagnostic quantities and the condition of the cables. Dissipation factor, insulation resistance and capacitance cover a broad range of values, but are apparently unrelated to cable condition. Similarly, cables with the highest breakdown voltages exhibit varying degrees of PD, as do the cables with the lower breakdown voltages. Note that the cable breakdown voltages, whether ac or dc, were recorded at values substantially above operating line to ground voltage. However, in a phase-to-phase test, the applied stress is reduced because of the increased insulation. In practice, it would be quite difficult to predict whether any of the cables with the lower breakdown voltage would ever fail under normal operating voltage.

Table 1. AC & DC Breakdown Results

Cable	Phase	Unshielded Cables Breakdown* (kV)		Shielded Cables Breakdown* (kV)	
		AC	DC	AC	DC
BF-PM	R W B	60 85 75		FO 86 FO 70 76	
C-PM	R W B		WS WS WS	85 80 80	WS
CCW-PM[a]	R W B	40 damaged by R		damaged by 40	W BD 32
	R W B			65 65 75	WS
ID-FM	R W B	45 damaged by R		damaged by 40	W BD 43

* WS: withstand, FO: flashover
[a] CCW-PM Cable was tested in two sections in the laboratory

Table 2. Results for Measurements of Partial Discharge (PD) Inception (DIV), Extinction (DEV) Voltages and Magnitudes

Cable	Phase	Unshielded Cables DIV (kV)	DEV (kV)	PD @ 6 kV (mV)		Shielded Cables DIV (kV)	DEV (kV)	PD @ 6 kV (mV)	
BF-PM	R W B	no	PD to	2.3 kV					
C-PM	R W B	 4.3 5.6	no 3.7 5.0	PD +30 +10	 -20 -10	5.4 5.8 5.2	5.2 4.2 4.7	+50 +50 +40	-35 -40 -40
CCW-PM[a]	R W B	no	PD to	4 kV		6.0 5.6 5.4	5.6 5.2 5.1	+40 +30 +50	-30 -20 -40
	R W B					no PD 4.7 no PD	to 4.1 to	6 kV +30 6 kV	-40
ID-FM	R W B	 6.0	no 5.8 no	PD +5 PD	 -5	5.4 4.8 5.2	5.2 4.2 4.7	+50 +50 +40	-35 -40 -40

[a] CCW-PM Cable was tested in two sections in the laboratory

Table 3. Dissipation Factor (DF) Measurements

Cable	Phase	Unshielded Cables DF (%)		Shielded Cables DF (%)	
		1 kV	2.3 kV	1 kV	2.3 kV
BF-PM	R	1.6	1.5	2.9	2.9
	W	1.6	1.5	2.9	2.9
	B	1.7	1.5	2.9	2.8
C-PM	R	12.3	12.9	13.7	13.3
	W	6.2	6.1	13.7	13.3
	B	6.3	6.0	13.1	12.8
CCW-PM[a]	R	3.8	3.2	7.3	7.0
	W	4.4	5.7	7.0	6.9
	B	3.0	3.2	6.7	6.6
	R			1.5	1.9
	W*				
	B			2.8	2.4
ID-FM	R	10.0	10.2	1.4	1.6
	W	10.0	10.6	1.5	1.7
	B	9.9	10.1	1.3	1.5

[a] CCW-PM Cable was tested in two sections in the laboratory
* could not balance bridge

Table 4. Results for Cable Capacitance Measurements

Cable	Phase	Unshielded Cables Capacitance (nF)		Shielded Cables Capacitance (nF)	
		1 kV	2.3 kV	1 kV	2.3 kV
BF-PM	R	1.2	1.2	1.9	1.9
	W	1.3	1.3	1.9	1.9
	B	1.3	1.2	1.9	1.9
C-PM	R	6.3	6.0	2.8	3.1
	W	6.2	6.1	2.9	3.1
	B	6.3	6.0	2.7	3.0
CCW-PM[a]	R	3.8	3.2	3.9	4.1
	W	4.4	5.7	3.9	4.1
	B	3.0	3.2	3.9	4.1
	R			4.4	4.6
	W*				
	B			4.3	4.5
ID-FM	R	3.8	3.2	4.2	4.4
	W	4.4	5.7	4.2	4.5
	B	3.0	3.2	4.1	4.4

[a] CCW-PM Cable was tested in two sections in the laboratory
* could not balance bridge

Table 5. Results for Insulation Resistance (IR) and Polarization Index (PI) Measurements

Cable	Phase	Unshielded Cables		Shielded Cables	
		IR (TΩ)	PI (10 min)	IR (TΩ)	PI (10 min)
BF-PM	R	0.5	4	1.5	2.0
	W	0.4	7	0.2	10.5
	B	0.3	5	0.2	8.0
C-PM	R	140	0.9	0.001	1.0
	W	120	0.8	0.001	0.9
	B	200	0.4	0.001	1.0
CCW-PM*	R	19	0.2	0.002	1.0
	W	>200	-	0.002	1.0
	B	>200	-	0.002	1.1
	R			0.070	1.6
	W			0.002	2.3
	B			0.040	1.9
ID-FM	R	>200	-	0.001	1.0
	W	200	0.7	0.001	1.0
	B	>200	-	0.001	1.0

* CCW-Cable was tested in two sections in the laboratory

In attempting to provide an overall assessment of cable condition and to extrapolate to the other station cables of interest, it becomes apparent that degradation by thermal processes was of little consequence in those cables. However, exposure to moist environments has led to a substantial decrease in ac breakdown strength. While no breakdown has yet occurred at operating voltage, it is reasonable to assume that this would ultimately happen. If the aging mechanism, water treeing, was correctly identified it can be assumed that the same problem would be found on other 5 kV cables in underground/wet locations. 600 V, and lower voltage cables, which operate at much reduced electrical stress would not be affected by this phenomenon. With the possible exception of local overheating, the conditions of the lower voltage cables would thus be expected to be satisfactory.

CONCLUSIONS

Four unshielded pump and fan motor cables were tested in an effort to assess their condition after approximately 25 years of service. While the cables were unshielded and thus lacked a well-defined, continuous ground plane, the results obtained here indicate that for multi-conductor configurations (e.g., triplex) testing phase-to-phase was a realistic alternative by providing a better defined stress across the insulation. Good agreement was obtained between ac and dc breakdowns obtained in-situ, phase-to-phase, and the same measurements repeated in the laboratory in a shielded configuration. None of the conventional diagnostic measurements (dc insulation resistance and polarization index, partial discharge, capacitance, dissipation factor) was sensitive to the cable deterioration.

Exposure to a moist environment and the postulated water treeing have caused a substantial decrease in ac breakdown strength. The same problems will very likely be found on other 5 kV cables in underground/wet locations and these cables should be replaced. Six hundred volts, and lower voltage cables, which operate at much reduced electrical stress would not be affected by this degradation phenomenon. With the possible exception of local overheating, the conditions of the lower voltage cables would thus be expected to be satisfactory.

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